Chapter A8: Characterization of CWIS Impacts by Water Body Type

The environmental impacts of cooling water intake structures (CWISs) are closely tied to the biological productivity of the water body from which cooling water is withdrawn. This chapter discusses CWIS impacts and potential benefits of § 316(b) regulation for specific water body types based on data compiled by EPA from existing studies. The data presented are numbers of organisms that are directly impinged or entrained. While EPA recognizes that impingement and entrainment losses may result in indirect effects on populations and other higher levels of biological organization, this chapter focuses on impingement and entrainment because these are the direct biological impacts that result from the withdrawal of cooling water by CWIS. Water body types discussed in this chapter include rivers and streams, lakes and reservoirs (excluding the Great Lakes), the Great Lakes, oceans, and estuaries. Habitats of particular biological sensitivity are highlighted within each type.

CHAPTER CONTENTS

A8-1 Development of a Database of I&E Rates

A8-1.1 Data Compilation

To estimate the relative magnitude of impingement and entrainment (I&E) for different species and water body types, EPA compiled I&E data from 107 documents representing a variety of sources, including previous §316(b) studies, critical reviews of §316(b) studies, biomonitoring and aquatic ecology studies, technology implementation studies, and data compilations. In total, data were compiled for 98 steam electric facilities (36 river facilities, 9 lake/reservoir facilities, 19 facilities on the Great Lakes, 22 estuarine facilities, and 12 ocean facilities). Design intake flows at these facilities ranged from a low of 19.7 to a high of 3,315.6 MGD.

EPA notes that most of these studies were completed by the facilities in the mid-1970s using methods that are now outmoded. A number of the methods used probably resulted in an underestimate of losses. For example, many studies did not adjust I&E sampling data for factors such as collection efficiency. Because of such methodological weaknesses, EPA believes that studies such as those discussed here should only be used to gauge the relative magnitude of impingement and entrainment losses. Any further analysis of the data should be accompanied by a detailed evaluation of study methods and supplemented with additional data as needed.

For the present objective of understanding the potential magnitude of I&E, EPA aggregated the data in the studies that were available to EPA in a series of steps to derive average annual impingement and entrainment rates, on a per facility basis, for different species and water body types. First, the data for each species were summed across all units of a facility and averaged across years (e.g., 1972 to 1976). Losses were then averaged by species for all facilities in the database on a given water body type to derive species-specific and water body-specific mean annual I&E rates. Finally, mean annual I&E rates were ranked, and rates for the top 15 species were used for subsequent data presentation.

A8-1.2 Data Uncertainties and Potential Biases

A number of data uncertainties and potential biases are associated with the I&E data that EPA evaluated. As with any ecological data, natural environmental variability makes it difficult to detect ecological impacts and identify cause-effect relationships even in cases where study methods are as accurate and reliable as possible. For example, I&E rates for any given population will vary with changes in environmental conditions that influence annual variation in recruitment. As a result, it can be difficult to determine the relative role of I&E mortality in population fluctuations.

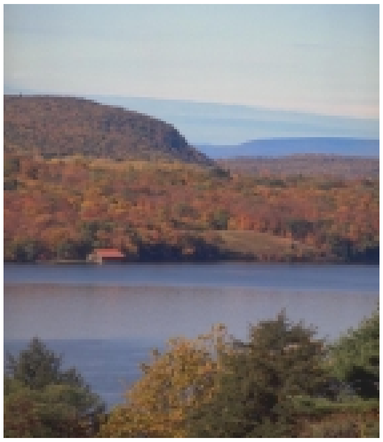
In addition to the influence of natural variability, data uncertainties result from measurement errors, some of which are unavoidable. In addition to the inefficiency of sampling gear, much of the data presented here does not account for variations in collection and analytical methods or changes in the number of units in operation or technologies in use.

Potential biases in the data were also difficult to control. For example, many studies presented data for only a subset of "representative" species, which may lead to an underestimation of total I&E. On the other hand, the entrainment estimates obtained from EPA's database do not take into account the high natural mortality of egg and larval stages and therefore are likely to be biased upwards. However, this bias was unavoidable because most of the source documents from which the database was derived did not estimate losses of early life stages as an equivalent number of adults, or provide information for making such calculations.[1] In the absence of information for adjusting egg losses on this basis, EPA chose to include eggs and larvae in the entrainment estimates to avoid underestimating age 0 losses.

With these caveats in mind, the following sections present the results of EPA's data compilation. The data are grouped by water body type and are presented in summary tables that indicate the range of losses for the 15 species with the highest I&E rates based on the limited subset of data available to EPA. I&E losses are expressed as mean annual numbers on a per facility basis. Because the data do not represent a random sample of I&E losses, it was not appropriate to summarize the data statistically. It is also important to stress that because the data are not a statistical sample, the data presented here may not reflect the true magnitude of losses. Thus, the data should be viewed only as general indicators of the potential range of I&E.

A8-2 CWIS Impingement and Entrainment Impacts in Rivers and Streams

Freshwater rivers and streams are free-flowing bodies of water that do no receive significant inflows of water from oceans or bays (Hynes, 1970; Allan, 1995). Current is typically highest in the center of a river and rapidly drops toward the edges and at depth because of increased friction with river banks and the bottom. Close to and at the bottom, the current can become minimal. The range of flow conditions in undammed rivers helps explain why fish with very different habitat requirements can co-exist within the same stretch of surface water (Matthews, 1998).



In general, the shoreline areas along river banks support a high diversity of aquatic life. These are areas where light penetrates to the bottom and supports the growth of rooted vegetation. Suspended solids tend to settle along shorelines where the current slows, creating shallow, weedy areas that attract aquatic life. Riparian vegetation, if present, also provides cover and shade. Such areas represent important feeding, resting, spawning, and nursery habitats for many aquatic species. In temperate regions, the number of impingeable and entrainable organisms in the littoral zone of rivers increases during the spring and early summer when most riverine fish species reproduce. This concentration of aquatic organisms along river shorelines in turn attracts wading birds and other kinds of wildlife.

The data compiled by EPA indicate that fish species such as common carp (*Cyprinus carpio*), yellow perch (*Perca flavescens*), white bass (*Morone chrysops*), freshwater drum (*Aplodinotus grunniens)*, gizzard shad (*Dorosoma cepedianum*), and alewife (*Alosa pseudoharengus*) are the main fishes harmed by CWIS located in rivers Table A8-1 shows, in order of the greatest to least impact, the annual entrainment of eggs, larvae, and juvenile fish in rivers. Table A8-2 shows, in order of greatest to least impact, the annual impingement in rivers for all age classes combined (mostly juveniles

[1] For species for which sufficient life history information is available, the Equivalent Adult Model (EAM) can be used to predict the number of individuals that would have survived to adulthood each year if entrainment at egg or larval stages had not occurred (Horst, 1975b; Goodyear, C.P., 1978). The resulting estimate is known as the number of "equivalent adults."

and young adults). These species occur in nearshore areas and/or have pelagic early life stages, traits that greatly increase their susceptibility to I&E.

Table A8-1: Annual Entrainment of Eggs, Larvae and Juvenile Fish in Rivers

Common Name	Scientific Name	Number of Facilities	Mean Annual Entrainment per Facility (fish/year)	Range
common carp	*Cyprinus carpio*	7	20,500,000	859,000 - 79,400,000
yellow perch	*Perca flavescens*	4	13,100,000	434,000 - 50,400,000
white bass	*Morone chrysops*	4	12,800,000	69,400 - 49,600,000
freshwater drum	*Aplodinotus grunniens*	5	12,800,000	38,200 - 40,500,000
gizzard shad	*Dorosoma cepedianum*	4	7,680,000	45,800 - 24,700,000
shiner	*Notropis* spp.	4	3,540,000	191,000 - 13,000,000
channel catfish	*Ictalurus punctatus*	5	3,110,000	19,100 - 14,900,000
bluntnose minnow	*Pimephales notatus*	1	2,050,000	---
black bass	*Micropterus* spp.	1	1,900,000	---
rainbow smelt	*Osmerus mordax*	1	1,330,000	---
minnow	*Pimephales* spp.	1	1,040,000	---
sunfish	*Lepomis* spp.	5	976,000	4,230 - 4,660,000
emerald shiner	*Notropis atherinoides*	3	722,000	166,000 - 1,480,000
white sucker	*Catostomus commersoni*	5	704,000	20,700 - 2,860,000
mimic shiner	*Notropis volucellus*	2	406,000	30,100 - 781,000

Sources: Hicks, 1977; Cole, 1978; Geo-Marine Inc., 1978; Goodyear, C.D., 1978; Potter, 1978; Cincinnati Gas & Electric Company, 1979; Potter et al., 1979a, 1979b, 1979c, 1979d; Cherry and Currie, 1998; Lewis and Seegert, 1998.

Table A8-2: Annual Impingement in the Rivers for All Age Classes

Common Name	Scientific Name	Number of Facilities	Mean Annual Impingement per Facility (fish/year)	Range
threadfin shad	*Dorosoma petenense*	3	1,030,000	199 - 3,050,000
gizzard shad	*Dorosoma cepedianum*	25	248,000	3,080 - 1,480,000
shiner	*Notropis* spp.	4	121,000	28 - 486,000
alewife	*Alosa pseudoharengus*	13	73,200	199 - 237,000
white perch	*Morone americana*	3	66,400	27,100 - 112,000
yellow perch	*Perca flavescens*	18	40,600	13 - 374,000
spottail shiner	*Notropis hudsonius*	10	28,500	10 - 117,000
freshwater drum	*Aplodinotus grunniens*	24	19,900	8 - 176,000
rainbow smelt	*Osmerus mordax*	11	19,700	7 - 119,000
skipjack herring	*Alosa chrysochons*	7	17,900	52 - 89,000
white bass	*Morone chrysops*	19	11,500	21 - 188,000
trout perch	*Percopsis omiscomaycus*	13	9,100	38 - 49,800
emerald shiner	*Notropis atherinoides*	17	7,600	109 - 36,100
blue catfish	*Ictalurus furcatus*	2	5,370	42 - 10,700
channel catfish	*Ictalurus punctatus*	23	3,130	3 - 25,600

Sources: Benda and Houtcooper, 1977; Freeman and Sharma, 1977; Hicks, 1977; Sharma and Freeman, 1977; Stupka and Sharma, 1977; Energy Impacts Associates Inc., 1978b; Geo-Marine Inc., 1978; Goodyear, C.D., 1978; Potter, 1978; Cincinnati Gas & Electric Company, 1979; Potter et al., 1979a, 1979b, 1979c, 1979d; Van Winkle et al., 1980; EA Science and Technology, 1987; Cherry and Currie, 1998; Lohner, 1998; Michaud, 1998.

A8-3 CWIS Impingement and Entrainment Impacts in Lakes and Reservoirs

Lakes are inland bodies of open water located in natural depressions (Goldman and Horne, 1983). Lakes are fed by rivers, streams, springs, and/or local precipitation. The residence time of water in lakes can be weeks, months, or even years, depending on the size and volume of the lake. Water currents in lakes are small or negligible compared to rivers, and are most noticeable near lake inlets and outlets.

Larger lakes are divided into three general zones – the littoral zone (shoreline areas where light penetrates to the bottom), the limnetic zone (the surface layer where most photosynthesis takes place), and the profundal zone (relatively deeper and colder offshore area) (Goldman and Horne, 1983). Each zone differs in its biological productivity and species diversity and hence in the potential magnitude of I&E. The importance of these zones in relation to potential I&E impacts of CWIS are discussed below.

The highly productive littoral zone extends farther and deeper in clear lakes than in turbid lakes. In small, shallow lakes, the littoral zone can be quite extensive and even include the entire water body. As along river banks, this zone supports high primary productivity and biological diversity. It is used by a host of fish species, benthic invertebrates, and zooplankton for feeding, resting, and reproduction, and as nursery habitat. Many fish species adapted to living in the colder profundal zone also move to shallower in-shore areas to spawn, e.g., lake trout (*Salmo namycush*) and various deep water sculpin species (*Cottus* spp.).

Many fish species spend most of their early development in and around the littoral zone of lakes. These shallow waters warm up rapidly in spring and summer, offer a variety of different habitats (submerged plants, boulders, logs, etc.) in which to hide or feed, and stay well-oxygenated throughout the year. Typically, the littoral zone is a major contributor to the total primary productivity of lakes (Goldman and Horne, 1983).

The limnetic zone is the surface layer of a lake. The vast majority of light that enters the water column is absorbed in this layer. In contrast to the high biological activity observed in the nearshore littoral zone, the offshore limnetic zone supports fewer species of fish and invertebrates. However, during certain times of year, some fish and invertebrate species that spend the daylight hours hiding on the bottom rise to the surface of the limnetic zone at night to feed and reproduce. Adult fish may migrate through the limnetic zone during seasonal spawning migrations. The juvenile stages of numerous aquatic insects — such as caddisflies, stoneflies, mayflies, dragonflies, and damselflies — develop in sediments at the bottom of lakes but move through the limnetic zone to reach the surface and fly away. This activity attracts foraging fish.

The profundal zone is the deeper, colder area of a lake. Rooted plants are absent because insufficient light penetrates at these depths. For the same reason, primary productivity by phytoplankton is minimal. A well-oxygenated profundal zone can support a variety of benthic invertebrates or cold-water fish, e.g., brown trout (*Salmo trutta*), lake trout, ciscoes (*Coregonus* spp.). With few exceptions (such as ciscos), these species seek out shallower areas to spawn, either in littoral areas or in adjacent rivers and streams, where they may become susceptible to I&E at CWIS.

Most of the larger rivers in the United States have one or more dams that create artificial lakes or reservoirs. Reservoirs have some characteristics that mimic those of natural lakes, but large reservoirs differ from most lakes in that they obtain most of their water from a large river instead of from groundwater recharge or from smaller creeks and streams.

The fish species composition in reservoirs may or may not reflect the native assemblages found in the pre-dammed river. Dams create two significant changes to the local aquatic ecosystem that can alter the original species composition:
(1) blockages that prevent anadromous species from migrating upstream, and (2) altered hydrologic regimes that can eliminate species that cannot readily adapt to the resulting changes in flow and habitat.

Reservoirs typically support littoral zones, limnetic zones, and profundal zones, and the same concepts outlined above for lakes apply to these bodies of water. For example, compared to the profundal zone, the littoral zone along the edges of reservoirs supports greater biological diversity and provides prime habitat for spawning, feeding, resting, and protection for numerous fish and zooplankton species. However, there are also several differences. Reservoirs often lack extensive shallow areas along their edges because their banks have been engineered or raised to contain extra water and prevent flooding. In mountainous areas, the banks of reservoirs may be quite steep and drop off precipitously with little or no littoral zone. As with lakes and rivers, however, CWIS located in shallower water have a higher probability of entraining or impinging organisms.

Results of EPA's data compilation indicate that fish species most commonly affected by CWIS located on lakes and reservoirs are the same as the riverine species that are most susceptible, including alewife, drum (*Aplondinotus* spp.), and gizzard shad (*Dorsoma cepedianum*) (Tables A8-3 and A8-4).

Table A8-3: Annual Entrainment of Eggs, Larvae and Juvenile Fish in Reservoirs and Lakes (excluding the Great Lakes)

Common Name	Scientific Name	Number of Facilities	Mean Annual Entrainment per Facility (fish/year)
drum	*Aplondinotus* spp.	1	15,600,000
sunfish	*Lepomis* spp.	1	10,600,000
gizzard shad	*Dorosoma cepedianum*	1	9,550,000
crappie	*Pomoxis* spp.	1	8,500,000
alewife	*Alosa pseudoharengus*	1	1,730,000

Sources: Michaud, 1998; Spicer et al., 1998.

Table A8-4: Annual Impingement in Reservoirs and Lakes (excluding the Great Lakes) for All Age Classes Combined

Common Name	Scientific Name	Number of Facilities	Mean Annual Impingement per Facility (fish/year)	Range
threadfin shad	*Dorosoma petenense*	4	678,000	203,000 - 1,370,000
alewife	*Alosa pseudoharengus*	4	201,000	33,100 - 514,000
skipjack herring	*Alosa chrysochons*	1	115,000	---
bluegill	*Lepomis macrochirus*	6	48,600	468 - 277,000
gizzard shad	*Dorosoma cepedianum*	5	41,100	829 - 80,700
warmouth sunfish	*Lepomis gulosus*	4	39,400	31 - 157,000
yellow perch	*Perca flavescens*	2	38,900	502 - 114,000
freshwater drum	*Aplodinotus grunniens*	4	37,500	8 - 150,000
silver chub	*Hybopsis storeriana*	1	18,200	---
black bullhead	*Ictalurus melas*	3	10,300	171 - 30,300
trout perch	*Percopsis omiscomaycus*	2	8,750	691 - 16,800
northern pike	*Esox lucius*	2	7,180	154 - 14,200
blue catfish	*Ictalurus furcatus*	1	3,350	---
paddlefish	*Polyodon spathula*	2	3,160	1,940 - 4,380
inland (tidewater) silverside	*Menidia beryllina*	1	3,100	---

Sources: Tennessee Division of Forestry, Fisheries, and Wildlife Development, 1976; Benda and Houtcooper, 1977; Freeman and Sharma, 1977; Sharma and Freeman, 1977; Tennessee Valley Authority, 1977; Michaud, 1998; Spicer et al., 1998.

A8-4 CWIS Impingement and Entrainment Impacts in the Great Lakes

The Great Lakes were carved out by glaciers during the last ice age (Bailey and Smith, 1981). They contain nearly 20% of the earth's fresh water, or about 23,000 km^3 (5,500 cu. mi.) of water, covering a total area of 244,000 km^2 (94,000 sq. mi.). There are five Great Lakes: Lake Superior, Lake Michigan, Lake Huron, Lake Erie, and Lake Ontario. Although part of a single system, each lake has distinct characteristics. Lake Superior is the largest by volume, with a retention time of 191 years, followed by Lake Michigan, Lake Huron, Lake Erie, and Lake Ontario.

Water temperatures in the Great Lakes strongly influence the physiological processes of aquatic organisms, affecting growth, reproduction, survival, and species temporal and spatial distribution. During the spring, many fish species inhabit shallow, warmer waters where temperatures are closer to their thermal optimum. As water temperatures increase, these species migrate to deeper water. For species that are near the northern limit of their range, the availability of shallow, sheltered habitats that warm early in the spring is probably essential for survival (Lane et al., 1996a). For other species, using warmer littoral areas increases the growing season and may significantly increase production.

Some 80% of Great Lakes fishes use the littoral zone for at least part of the year (Lane et al., 1996a). Of 139 Great Lakes fish species reviewed by Lane et al. (1996b), all but the deepwater ciscoes and deepwater sculpin (*Myxocephalus thompsoni*) use waters less than 10 m deep as nursery habitat.

A large number of thermal-electric plants located on the Great Lakes draw their cooling water from the littoral zone, resulting in high I&E of several fish species of commercial, recreational, and ecological importance, including alewife, gizzard shad, yellow perch, rainbow smelt, and lake trout (Tables A8-5 to A8-8).

Table A8-5: Annual Entrainment of Eggs, Larvae and Juvenile Fish in the Great Lakes

Common Name	Scientific Name	Number of Facilities	Mean Annual Entrainment per Facility (fish/year)	Range
alewife	*Alosa pseudoharengus*	5	526,000,000	3,930,000 - 1,360,000,000
rainbow smelt	*Osmerus mordax*	5	90,500,000	424,000 - 438,000,000
lake trout	*Salmo namaycush*	1	116,000	---

Sources: Texas Instruments Inc. and Lawler, Matusky, and Skelly Engineers, 1978; Michaud, 1998.

Table A8-6: Annual Entrainment of Larval Fish in the Great Lakes by Lake

Lake	Number of Facilities	Total Annual Entrainment (fish/year)
Erie	16	255,348,164
Michigan	25	196,307,405
Ontario	11	176,285,758
Huron	6	81,462,440
Superior	14	4,256,707

Source: Kelso and Milburn, 1979.

Table A8-7: Annual Impingement in the Great Lakes for All Age Classes Combined

Common Name	Scientific Name	Number of Facilities	Mean Annual Impingement per Facility (fish/year)	Range
alewife	*Alosa pseudoharengus*	15	1,470,000	355 - 5,740,000
gizzard shad	*Dorosoma cepedianum*	6	185,000	25 - 946,000
rainbow smelt	*Osmerus mordax*	15	118,000	78 - 549,000
threespine stickleback	*Gasterosteus aculeatus*	3	60,600	23,200 - 86,200
yellow perch	*Perca flavescens*	9	29,900	58 - 127,000
spottail shiner	*Notropis hudsonius*	8	22,100	5 - 62,000
freshwater drum	*Aplodinotus grunniens*	4	18,700	2 - 74,800
emerald shiner	*Notropis atherinoides*	4	7,250	3 - 28,600
trout perch	*Percopsis omiscomaycus*	5	5,630	30 - 23,900
bloater	*Coregonus hoyi*	2	4,980	3,620 - 6,340
white bass	*Morone chrysops*	1	4,820	--
slimy sculpin	*Cottus cognatus*	4	3,330	795 - 5,800
goldfish	*Carassius auratus*	3	2,620	4 - 7,690
mottled sculpin	*Cottus bairdi*	3	1,970	625 - 3,450
common carp	*Cyprinus carpio*	4	1,110	16 - 4,180
pumpkinseed	*Lepomis gibbosus*	4	1,060	14 - 3,920

Sources: Benda and Houtcooper, 1977; Sharma and Freeman, 1977; Texas Instruments Inc. and Lawler, Matusky, and Skelly Engineers, 1978; Thurber and Jude, 1985; Lawler Matusky & Skelly Engineers, 1993; Michaud, 1998.

Table A8-8: Annual Impingement of Fish in the Great Lakes

Lake	Number of Facilities	Total Annual Impingement (fish/year)
Erie	16	22,961,915
Michigan	25	15,377,339
Ontario	11	14,483,271
Huron	6	7,096,053
Superior	14	243,683

Source: Kelso and Milburn, 1979.

The I&E estimates of Kelso and Milburn (1979) presented in Tables A8-6 and A8-8 were derived using methods that differed in a number of ways from EPA's estimation methods, and therefore the data are not strictly comparable. First, the Kelso and Milburn (1979) data represent total annual losses per lake, whereas EPA's estimates are on a per facility basis. In addition, the estimates of Kelso and Milburn (1979) are based on extrapolation of losses to facilities for which data were unavailable using regression equations relating losses to plant size.

Despite the differences in estimation methods, when converted to an annual average per facility, the impingement estimates of Kelso and Milburn (1979) are within the range of EPA's estimates. For example, Kelso and Milburn's (1979) estimated average annual impingement of 675,980 fish per facility is comparable to EPA's high estimate of 1,470,000 for alewife.

On the other hand, EPA's entrainment estimates include eggs and larvae and are therefore substantially larger than those of Kelso and Milburn (1979), which are based on converting eggs and larvae to an equivalent number of fish. Because of the high natural mortality of fish eggs and larvae, entrainment losses expressed as the number that would have survived to become fish are much smaller than the original number of eggs and larvae entrained (Horst, 1975b; Goodyear, C.P., 1978). Nonetheless, when viewed together, the two types of estimates give an indication of the possible upper and lower bounds of annual entrainment per facility (e.g., an annual average of 8,018,657 fish based on Kelso and Milburn's data compared to EPA's highest estimate of 526,000,000 organisms based on the average for alewife).

A8-5 CWIS Impingement and Entrainment Impacts in Estuaries

Estuaries are semi-enclosed bodies of water that have a an unimpaired natural connection with the open ocean and within which sea water is diluted with fresh water derived from land (Day et al., 1989). The dynamic interactions among freshwater and marine environments in estuaries result in a rich array of habitats used by both terrestrial and aquatic species. Because of the high biological productivity and sensitivity of estuaries, adverse environmental impacts are more likely to occur at CWIS located in estuaries than in other water body types.

Numerous commercially, recreationally, and ecologically important species of fish and shellfish spend part or all of their life cycle within estuaries. Marine species that spawn offshore take advantage of prevailing inshore currents to transport their eggs, larvae, or juveniles into estuaries where they hatch or mature. Inshore areas along the edges of estuaries support high rates of primary productivity and are used by numerous aquatic species for feeding and as nursery habitats. This high level of biological activity makes these shallow littoral zone habitats highly susceptible to I&E impacts from CWIS.

Estuarine species that show the highest rates of I&E in the studies reviewed by EPA include bay anchovy (*Anchoa mitchilli*), tautog (*Tautoga onitis*), Atlantic menhaden (*Brevoortia tyrannus*), gulf menhaden (*Brevoortia patronus*), winter flounder (*Pleuronectes americanus*), and weakfish (*Cynoscion regalis*) (Tables A8-9 and A8-10).

During spring, summer and fall, various life stages of these and other estuarine fishes show considerable migratory activity. Adults move in from the ocean to spawn in the marine, brackish, or freshwater portions of estuaries or tributary rivers; the eggs and larvae can be planktonic and move about with prevailing currents or by using selective tidal transport; juveniles actively move upstream or downstream in search of optimal nursery habitat; and young adult anadromous fish move out of freshwater areas and into the ocean to reach sexual maturity. Because of the many complex movements of estuarine-dependent species, a CWIS located in an estuary can harm both resident and migratory species as well as related freshwater, estuarine, and marine food webs.

Table A8-9: Annual Entrainment of Eggs, Larvae, and Juvenile Fish in Estuaries

Common Name	Scientific Name	Number of Facilities	Mean Annual Entrainment per Facility (fish/year)	Range
bay anchovy	*Anchoa mitchilli*	2	18,300,000,000	12,300,000,000 - 24,400,000,000
tautog	*Tautoga onitis*	1	6,100,000,000	---
Atlantic menhaden	*Brevoortia tyrannus*	2	3,160,000,000	50,400,000 - 6,260,000,000
winter flounder	*Pleuronectes americanus*	1	952,000,000	---
weakfish	*Cynoscion regalis*	2	339,000,000	99,100,000 - 579,000,000
hogchoker	*Trinectes maculatus*	1	241,000,000	---
Atlantic croaker	*Micropogonias undulatus*	1	48,500,000	---
striped bass	*Morone saxatilis*	4	19,200,000	111,000 - 74,800,000
white perch	*Morone americana*	4	16,600,000	87,700 - 65,700,000
spot	*Leiostomus xanthurus*	1	11,400,000	---
blueback herring	*Alosa aestivalis*	1	10,200,000	---
alewife	*Alosa pseudoharengus*	1	2,580,000	---
Atlantic tomcod	*Microgadus tomcod*	3	2,380,000	2,070 - 7,030,000
American shad	*Alosa sapidissima*	1	1,810,000	---

Sources: U.S. EPA, 1982a; Lawler Matusky & Skelly Engineers, 1993; DeHart, 1994; PSEG, 1999f.

Table A8-10: Annual Impingement in Estuaries for All Age Classes Combined

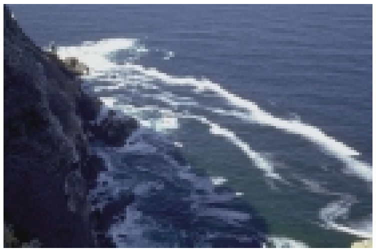
Common Name	Scientific Name	Number of Facilities	Mean Annual Impingement per Facility (fish/year)	Range
gulf menhaden	*Brevoortia patronus*	2	76,000,000	2,990,000 - 149,000,000
smooth flounder	*Liopsetta putnami*	1	3,320,000	--
threespine stickleback	*Gasterosteus aculeatus*	4	866,000	123 - 3,460,000
Atlantic menhaden	*Brevoortia tyrannus*	12	628,000	114 - 4,610,000
rainbow smelt	*Osmerus mordax*	4	510,000	737 - 2,000,000
bay anchovy	*Anchoa mitchilli*	9	450,000	1,700 - 2,750,000
weakfish	*Cynoscion regalis*	4	320,000	357 - 1,210,000
Atlantic croaker	*Micropogonias undulatus*	8	311,000	13 - 1,500,000
spot	*Leiostomus xanthurus*	10	270,000	176 - 647,000
blueback herring	*Alosa aestivalis*	7	205,000	1,170 - 962,000
white perch	*Morone americana*	14	200,000	287 - 1,380,000
threadfin shad	*Dorosoma petenense*	1	185,000	---
lake trout	*Salmo namaycush*	1	162,000	---
gizzard shad	*Dorosoma cepedianum*	6	125,000	2,058 - 715,000
silvery minnow	*Hybognathus nuchalis*	1	73,400	---

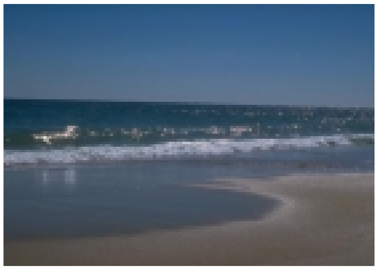
Sources: Consolidated Edison Company of New York Inc., 1975; Lawler Matusky & Skelly Engineers, 1975, 1976; Stupka and Sharma, 1977; Lawler et al., 1980; Texas Instruments Inc., 1980; Van Winkle et al., 1980; Consolidated Edison Company of New York Inc. and New York Power Authority, 1983; Normandeau Associates Inc., 1984; EA Science and Technology, 1987; Lawler Matusky & Skelly Engineers, 1991; Richkus and McLean, 1998; PSEG, 1999f; New York State Department of Environmental Conservation, 2000.

A8-6 CWIS Impingement and Entrainment Impacts in Oceans

Oceans are marine open coastal waters with salinity greater than or equal to 30 parts per thousand (Ross, 1995). CWIS in oceans are usually located over the continental shelf, a shallow shelf that slopes gently out from the coastline an average of 74 km (46 miles) to where the sea floor reaches a maximum depth of 200 m (660 ft) (Ross, 1995). The deep ocean extends beyond this region. The area over the continental shelf is known as the Neritic Province and the area over the deep ocean is the Oceanic Province (Meadows and Campbell, 1978).

Vertically, the upper, sunlit epipelagic zone over the continental shelf averages about 100 m in depth (Meadows and Campbell, 1978). This zone has pronounced light and temperature gradients that vary seasonally and influence the temporal and spatial distribution of marine organisms.





In oceans, the littoral zone encompasses the photic zone of the area over the continental shelf. As in other water body types, the littoral zone is where most marine organisms concentrate. The littoral zone of oceans is of particular concern in the context of § 316(b) because this biologically productive zone is also where most coastal utilities withdraw cooling water.

The morphology of the continental shelf along the U.S. coastline is quite varied (NRC, 1993). Along the Pacific coast of the United States the continental shelf is relatively narrow, ranging from 5 to 20 km (3 to 12 miles), and is cut by several steep-sided submarine canyons. As a result, the littoral zone along this coast tends to be narrow, shallow, and steep. In contrast, along most of the Atlantic coast of the United States, there is a wide, thick, and wedge-shaped shelf that extends as much as 250 km (155 miles) from shore, with the greatest widths generally opposite large rivers. Along the Gulf coast, the shelf ranges from 20 to 50 km (12 to 31 miles).

The potential for I&E at ocean facilities can be quite high if CWIS are located in the productive areas over the continental shelf where many species reproduce, or in nearshore areas that provide nursery habitat. In addition, the early life stages of many species are planktonic, and tides and currents can carry these organisms over large areas. The abundance of plankton in temperate regions is seasonal, with greater numbers in spring and summer and fewer numbers in winter.

An additional concern for ocean CWIS is the presence of marine mammals and reptiles, including threatened and endangered species of sea turtles. These species are known to enter submerged offshore CWIS and can drown once inside the intake tunnel.

In addition to many of the species discussed in the section on estuaries, other fish species found in near coastal waters that are of commercial, recreational, or ecological importance, and are particularly vulnerable to I&E, include silver perch (*Bairdiella chrysura*), cunner (*Tautogolabrus adspersus*), several anchovy species, scaled sardine (*Harengula jaguana)*, and queenfish (*Seriphus politus*) (Tables A8-11 and A8-12).

Table A8-11: Annual Entrainment of Eggs, Larvae, and Juvenile Fish in Oceans

Common Name	Scientific Name	Number of Facilities	Mean Annual Entrainment per Facility (fish/year)	Range
bay anchovy	*Anchoa mitchilli*	2	44,300,000,000	9,230,000,000 - 79,300,000,000
silver perch	*Bairdiella chrysura*	2	26,400,000,000	8,630,000 - 52,800,000,000
striped anchovy	*Anchoa hepsetus*	1	6,650,000,000	---
cunner	*Tautogolabrus adspersus*	2	1,620,000,000	33,900,000 - 3,200,000,000
scaled sardine	*Harengula jaguana*	1	1,210,000,000	---
tautog	*Tautoga onitis*	2	911,000,000	300,000 - 1,820,000,000
clown goby	*Microgobius gulosus*	1	803,000,000	---
code goby	*Gobiosoma robustum*	1	680,000,000	---
sheepshead	*Archosargus probatocephalus*	1	602,000,000	---
kingfish	*Menticirrhus* spp.	1	542,000,000	---
pigfish	*Orthopristis chrysoptera*	2	459,000,000	755,000 - 918,000,000
sand sea trout	*Cynoscion arenarius*	1	325,000,000	---
northern kingfish	*Menticirrhus saxatilis*	1	322,000,000	---
Atlantic mackerel	*Scomber scombrus*	1	312,000,000	---
Atlantic bumper	*Chloroscombrus chrysurus*	1	298,000,000	---

Sources: Conservation Consultants Inc., 1977; Stone & Webster Engineering Corporation, 1980a; Florida Power Corporation, 1985; Normandeau Associates Inc., 1994b; Jacobsen et al., 1998; Northeast Utilities Environmental Laboratory, 1999.

Table A8-12: Annual Impingement in Oceans for All Age Classes Combined

Common Name	Scientific Name	Number of Facilities	Mean Annual Impingement per Facility (fish/year)	Range
queenfish	*Seriphus politus*	2	201,000	19,800 - 382,000
polka-dot batfish	*Ogcocephalus radiatus*	1	74,500	---
bay anchovy	*Anchoa mitchilli*	2	49,500	11,000 - 87,900
northern anchovy	*Engraulis mordax*	2	36,900	26,600 - 47,200
deepbody anchovy	*Anchoa compressa*	2	35,300	34,200 - 36,400
spot	*Leiostomus xanthurus*	1	28,100	---
American sand lance	*Ammodytes americanus*	2	20,700	886 - 40,600
silver perch	*Bairdiella chrysura*	2	20,500	12,000 - 29,000
California grunion	*Caranx hippos*	1	18,300	---
topsmelt	*Atherinops affinis*	2	18,200	4,320 - 32,300
alewife	*Alosa pseudoharengus*	2	16,900	1,520 - 32,200
pinfish	*Lagodon rhomboides*	1	15,200	---
slough anchovy	*Anchoa delicatissima*	3	10,900	2,220 - 27,000
walleye surfperch	*Hyperprosopon argenteum*	1	10,200	---
Atlantic menhaden	*Brevoortia tyrannus*	3	7,500	861 - 20,400

Sources: Stone & Webster Engineering Corporation, 1977; Stupka and Sharma, 1977; Tetra Tech Inc., 1978; Stone and Webster Engineering Corporation, 1980a; Florida Power Corporation, 1985; Southern California Edison Company, 1987; SAIC, 1993; EA Engineering, Science and Technology, 1997; Jacobsen et al., 1998.

A8-7 Summary and Conclusions

The data evaluated by EPA indicate that fish species with free-floating, early life stages are those most susceptible to CWIS impacts. Such planktonic organisms lack the swimming ability to avoid being drawn into intake flows. Species that spawn in nearshore areas, have planktonic eggs and larvae, and are small as adults experience even greater impacts because both new recruits and the spawning adults are affected (e.g., bay anchovy in estuaries and oceans).

EPA's data review also indicates that fish species in estuaries and oceans experience the highest rates of I&E. These species tend to have planktonic eggs and larvae, and tidal currents carry planktonic organisms past intakes multiple times, increasing the probability of I&E. In addition, fish spawning and nursery areas are located throughout estuaries and near coastal waters, making it difficult to avoid locating intakes in areas where fish are present.